Total Maximum Daily Load (TMDL) Development for the Tongue River, Powder River, and Rosebud Creek Planning Areas

Modeling Approach Report

DRAFT

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1.0 INTRODUCTION

The Tongue River, Powder River, and Rosebud Creek watersheds encompass almost 20,000 square miles in the states of Wyoming and Montana. Various stream segments within these watersheds are designated as "water quality impaired" or "threatened" and require the development of Total Maximum Daily Loads (TMDLs); Appendix A displays all of the listed waters and their associated causes of impairment. On September 21, 2000, the United States District Court of Montana ordered the U.S. Environmental Protection Agency (USEPA) to work with the Montana Department of Environmental Quality (MDEQ) to develop and adopt a schedule to develop all necessary TMDLs for waters on Montana's 1996 Section 303(d) list by May 5, 2007. See, *Friends of the Wild Swan, Inc. et al.*, vs. *U.S. Environmental Protection Agency*, CV 97-35-M-DWM. In accordance with the original schedule, all necessary TMDLs for the Tongue River, Powder River, and Rosebud Creek watersheds were to be completed by December 31, 2006. However, the MDEQ has decided to accelerate the schedule for these watersheds to facilitate coordination between the TMDL program and ongoing efforts relative to development of coal-bed methane (CBM). The final target date for completion of all necessary TMDLs for these watersheds is now December 31, 2003.

The TMDL process identifies the maximum load of a pollutant (e.g., sediment, nutrient, metal) a waterbody is able to assimilate and fully support its designated uses, allocates portions of the maximum load to all sources, identifies the necessary controls that may be implemented voluntarily or through regulatory means, and describes a monitoring plan and associated corrective feedback loop to insure that uses are fully supported. A TMDL can also be viewed as the total amount of pollutant that a waterbody may receive from all sources without exceeding water quality standards. Montana's approach is to include TMDLs as a part of a comprehensive water quality restoration plan containing seven principal components:

1. Watershed characterization (e.g., hydrology, climate, vegetation, land use, ownership)
2. Description of impairments and applicable water quality standards
3. Pollutant source assessment and estimate of existing pollutant loads
4. Water quality goals (i.e., water quality targets and TMDLs)
5. Allocation
6. Restoration strategy
7. Monitoring Strategy

Previous reports have addressed the watershed characterization and preliminary impairment status components of the TMDL process (MDEQ 2003a; MDEQ, 2003b; MDEQ, 2003c). The purpose of this document is to explain the modeling approach that will be used to help further evaluate the impairment status as well as to address the source assessment, water quality goals, allocation, and restoration strategy components of the TMDL development process. Key questions that the modeling process will help answer include the following:

- What are the expected water quality conditions during periods for which no observed data are available (to aid in the impairment status decision)?
- What are the existing pollutant loads from each source category (e.g., natural or anthropogenic)?
- What are the existing pollutant loads from each subwatershed?
- What are the allowable pollutant loads?
- What are the potential benefits of various restoration strategies?

2.0 MODEL SELECTION

Two different types of models will be necessary to simulate conditions within the Tongue River, Powder River, and Rosebud Creek watersheds. A *watershed* model will be needed to address the generation of loads over the land surface and through groundwater contributions and can also be used to address the resulting impact on stream water quality. A separate *receiving water* model will be necessary to simulate conditions within the Tongue River Reservoir because of the inherent differences between stream and reservoir systems.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using the land-based calculations as input. Once a model has been adequately set up and calibrated for a watershed it can be used to quantify the existing loading of pollutants from subwatersheds or from land use categories. Models can also be used to assess the potential benefits of various restoration scenarios (e.g., implementation of certain best management practices).

Receiving water models are composed of a series of algorithms applied to characteristics data to simulate flow and water quality in a waterbody. The characteristics data, however, represent physical and chemical aspects of a lake, river, or estuary. These models vary from simple 1-dimensional models to complex 3-dimensional models capable of simulating water movement, salinity, temperature, sediment transport, and water quality.

2.1 Selection Criteria

The following criteria have been considered and addressed in selecting appropriate models for development of TMDLs in the Tongue, Powder and Rosebud Basins (expanding on classification of Mao, 1992):

- Technical Criteria
- Regulatory Criteria
- User Criteria

Technical criteria refer to the model's ability to simulate the physical system in question, including watershed and/or stream/reservoir characteristics/processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or procedural protocol. User criteria comprise the operational or economical constraints imposed by the end-user of the model and include factors such as hardware/software compatibility and financial resources. The following discussion details considerations within each of these categories specific to the Tongue River, Powder River, and Rosebud Creek watersheds.

2.1.1 Technical Criteria

Land use in the Tongue River, Powder River, and Rosebud Creek watersheds includes extensive areas of grasslands, rangelands, shrublands, and forest with limited residential development. Most agricultural and residential land uses are concentrated along the valley floors and much of the agriculture relies on irrigated water. Different potential sources of pollutants are associated with each of these land use types and activities (e.g., natural sources, livestock sources, streambank erosion, irrigation return flows, etc.) and each land use affects the hydrology of the watershed differently. Some of these sources may contribute relatively constant discharges of pollutants while others may be heavily influenced by snowmelt and rain events. Therefore the following considerations are critical to selecting an appropriate model:

- The model must be able to address a watershed with primarily rural land uses.
- The model must be able to address the pollutants of concern (e.g., TDS, sediment, pathogens, metals, nutrients).
- The model must be able to simulate the effects of irrigation on hydrology and pollutant loading.
- The model must provide adequate time-step estimation of flow and not over-simplify storm events to provide accurate representation of rainfall events and resulting peak runoff.
- The model must be capable of simulating various pollutant transport mechanisms (e.g., groundwater contributions, sheet flow, streambank erosion, etc.).
- The model must include an acceptable snowmelt routine.

2.1.2 Regulatory Criteria

A properly designed and applied model provides the source-response linkage component of the TMDL and enables accurate assessment of allowable loads and acceptable allocation decisions. A stream or reservoir's assimilative capacity is determined through adherence to the appropriate TMDL targets. Table 1 summarizes several considerations associated with the targets that are likely to be adopted for the Tongue River, Powder River, and Rosebud Creek TMDLs.

Table 1. Summary of TMDL targets likely to be used in the development of TMDLs for the Tongue River, Powder River, and Rosebud Creek watersheds.

Pollutant	Narrative or Numeric Criteria	Magnitude	Duration	Frequency
EC/TDS	Numeric	Varies by segment	Monthly Average and Instantaneous Maximum During Irrigation Season	Criteria is randomly exceeded by no more than 10 percent of the samples in a large dataset.
SAR	Numeric	Varies by segment	Monthly Average and Instantaneous Maximum During Irrigation Season	Criteria is randomly exceeded by no more than 10 percent of the samples in a large dataset.
Metals	Numeric	Varies by metal	4 Day Average (Chronic) and Instantaneous Maximum Year Round	No exceedance of acute or chronic standards, and/or the chronic standards are exceeded by less than 10 percent no more than once in a three-year period when measurements were taken at least four times/year (quarterly).
Fecal Coliforms	Numeric	200 and 400 coliforms per 100 mL	Instantaneous Maximum and 30-day geometric mean applied when the daily maximum water temperature is greater that 60 °F.	The geometric mean must be less than 200 coliforms per 100 mL and no more than 10 percent of the samples during a 30-day period shall exceed 400 coliforms per 100 mL.
Sediment	Narrative	TBD	TBD	TBD
Nutrients	Narrative	TBD	Monthly Average During Growing Season	Target is randomly exceeded by no more than 10 percent of the samples in a large dataset.

Pollutant	Narrative or Numeric Criteria	Magnitude	Duration	Frequency
Temperature	Narrative	Varies	Summer 7-day Maximum	Target is randomly exceeded by no more than 10 percent of the samples in a large dataset.

In selecting a modeling system, consideration must be given to the targets adopted for the TMDL. The selected model must be capable of simulating these water quality parameters using time-series simulation so that applicable averaging periods and peak levels can be determined and compared to numeric targets. For example, some models only provide annual or monthly output and would therefore be of little use in assessing compliance with targets that are expressed as instantaneous maximums, such as EC/TDS and SAR. The selected model must also be able to address seasonal variations in hydrology and water quality and critical conditions (i.e., periods when pollutant concentrations are at their highest) as required by the TMDL targets.

2.1.3 User Criteria

User criteria are determined by the needs, expectations, and resources of the stakeholders involved in the TMDL process (e.g., MDEQ, USEPA, tribes, irrigators, industry, state and local government officials). Due to the high profile nature of these TMDLs, it is clear that stakeholders will demand that the best science be used in determining the existing and allowable pollutant loads. Furthermore, modeling software must be compatible with existing hardware platforms, and due to future use for planning and permitting decisions, should be well-documented, tested, and accepted. Because MDEQ is a public agency the software should also be publicly available and not proprietary. Another consideration is that NPDES permitting decisions might be based on model output. Therefore MDEQ and/or USEPA permit writers should be able to use the model, or summarized model output, to assist in their activities.

From a resource perspective, the level of effort required to develop, calibrate, and apply the model must be commensurate with available funding, without compromising the ability to meet technical criteria. In addition to these primary criteria, the required time-frame for model development, application, and completion is important.

2.2 Description of the Recommend Models

2.2.1 Watershed Model

Tetra Tech is recommending that the Hydrologic Simulation Program - FORTRAN (HSPF) be used to support TMDL development in the Tongue River, Powder River, and Rosebud Creek watersheds. HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970's. During the past several years it has been used to develop hundreds of USEPA-approved TMDLs and it is generally considered the most advanced hydrologic and watershed loading model available. USEPA and Tetra Tech have recently upgraded the coding of the HSPF model to increase its speed and flexibility. The new version of the model is called the Loading Simulation Program in C++ (LSPC). LSPC integrates a geographical information system (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements. LSPC is proposed for this project because, as explained below, it best matches the required technical, regulatory, and user criteria described above.

The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford and Linsley, 1966), which was one of the pioneering watershed models developed in the 1960's. The HSPF framework is developed in a modular fashion with many different components that can be assembled in different ways, depending on the objectives of the study. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes.

All three of these modules include many submodules that calculate the various hydrologic and water quality processes in the watershed. Many options are available for both simplified and complex process formulations. Spatially, the watershed is divided into a series of subbasins representing the drainage areas that contribute to each of the stream reaches. These subbasins are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into the pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and groundwater flow contributions from each of the land segments and subbasins and routes them through the water courses using storage routing techniques. The stream/lake model includes precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals can also be accommodated. The stream network is constructed to represent all of the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Like the watershed components, several options are available for simulating water quality in the receiving waters. The simpler options consider transport through the waterways and represent all transformations and removal processes using simple first-order decay approaches. This method is appropriate for nutrients, using decay to represent the net loss due to all processes such as algal uptake, denitrification, and adsorption to sediments. However, the model also includes options for more detailed eutrophication approaches that include full nutrient cycles, different nutrient forms, and other constituents such as algae and dissolved oxygen that are important components of nutrient transformations in waterways. The framework is flexible and allows different combinations of constituents to be modeled depending on data availability and the objectives of the study.

Advantages to choosing HSPF/LSPC for this application include:

- Simulates all of the necessary constituents (TDS, nutrients, sediments, metals, fecal coliform, temperature)
- Applies to both rural and urban areas
- Allows long-term continuous simulations to predict hydrologic variability
- Provides adequate spatial resolution to evaluate loads to different receiving waters
- Provides adequate temporal resolution (i.e., hourly or daily) to facilitate a direct comparison to the TMDL targets
- Includes both surface runoff and groundwater baseflow conditions
- Simulates both point and nonpoint sources, including septic systems
- Allows evaluation of BMPs and land use changes through model parameter changes or direct simulation
- Provides storage of all geographic, modeling, and point source permit data in a Microsoft Access database and text file formats – thus data manipulation is efficient and straightforward.
- Presents no inherent limitations regarding the size and number of watersheds and streams that can be modeled.
- Can be easily linked to other models (advanced hydrodynamic and water quality models such as EFDC, WASP, or CE-QUAL-W2) in a modular fashion.

- LSPC can be easily modified to include additional features that are specific to the Tongue, Powder, and Rosebud Basins - such features include the best management practices (BMP) module or other management strategies that can influence the potential runoff and water quality loading characteristics of the watershed.
- LSPC provides post-processing and analytical tools designed specifically to support TMDL development and reporting requirements (including a TMDL calculator).

2.2.2 Reservoir Model

Tetra Tech is recommending that the CE-QUAL-W2 model be used to develop the TMDL for the Tongue River Reservoir. CE-QUAL-W2 (W2) is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model (Cole et al 2000). The model allows application to multiple branches for geometrically complex waterbodies (dendritic/branching reservoirs such as the Tongue River Reservoir) with variable grid spacing, time-variable boundary conditions, and multiple inflows and outflows from point/nonpoint sources and precipitation.

The two major components of the W2 model include hydrodynamics and water quality kinetics. Both of these components are coupled (i.e. the hydrodynamic output is used to drive the water quality at every timestep). This makes it very efficient to execute the model runs. The hydrodynamic portion of the model predicts water surface elevations, velocities, and temperature. The W2 model uses the ULTIMATE - QUICKEST numerical scheme for advection – dispersion computation. The ULTIMATE – QUICKEST numerical scheme is a third order finite difference scheme. This method reduces the numerical diffusion in the vertical direction to a minimum. The water quality portion of the model can simulate 21 constituents including dissolved oxygen (DO), nutrients, and phytoplankton interactions. Any combination of constituents can be simulated.

The W2 model was chosen over other available reservoir models for the following reasons:

- Simpler reservoir models, such as BATHTUB, EUTROMOD, or PHOSMOD, do not include the capability to simulate salinity and do not allow one to predict daily concentrations of dissolved oxygen (necessary to compare to the water quality standard).
- The simpler reservoir models are primarily empirical and do not include the capability to simulate cause-and-effect relationship between loading to and response in the reservoir.
- The W2 model can be easily linked to the HSPF/LSPC model (i.e., LSPC outputs can be used as inputs to W2 and vice versa).
- More advanced reservoir models, such as USEPA’s WASP/EUTRO5 model, do not have a hydrodynamic model to independently calculate the mass transport in the water column.
- The CE-QUAL-ICM and EFDC models are both 3-dimensional, thereby requiring a significant amount of data, which are beyond what is available for Tongue River Reservoir.

3.0 PROPOSED MODELING APPROACH

Development and application of the HSPF/LSPC model to address the project objectives will involve a number of important steps:

1. Watershed Segmentation and Boundary Conditions
2. Configuration of Key Model Components
3. Model Calibration and Validation
4. Model Simulation for Existing Conditions and Scenarios

3.1 Watershed Segmentation and Boundary Conditions

Watershed segmentation refers to the subdivision of each of the three watersheds into smaller, discrete subwatersheds for modeling and analysis. This subdivision will primarily be based on the stream networks and topographic variability, and secondarily on the locations of flow and water quality monitoring stations, consistency of hydrologic factors, land use consistency, and existing watershed boundaries (from previous studies or for management considerations).

A model's boundary condition refers to how it simulates flows and water quality at its most upstream point. Two options exist for specifying boundary conditions for this project and a decision has not yet been made regarding the preferred alternative. Option 1 would be to set the Montana/Wyoming state line as the upstream limit of the modeling for the Tongue River and Powder River watersheds (the Rosebud Creek watershed is located entirely within Montana). Only the watersheds below the state line would be physically represented in the model and inputs to the model at the state line would be based on existing flow and water quality data. There are several advantages to this approach which include:

- Efforts to date have focused on conditions within the state of Montana and a great deal of site-specific information has been or is being gathered regarding land uses, irrigation practices, soils, existing water quality, and potential future sources. A comparable amount of information is not currently available for conditions in Wyoming. Collecting such data might place a burden on existing time and funding resources.
- Similarly, efforts to date have focused on using the TMDL to evaluate the potential for future CBM development in Montana. Using the model to evaluate the impact of current and future CBM development in Wyoming would add another layer of complexity to the project.
- Others?

Option 2 would be to model the entire Tongue and Powder Rivers from their headwaters to their confluence with the Yellowstone River. Advantages to this approach include the following:

- Modeling the entire watershed would facilitate a more in-depth and integrated analysis of how conditions within Wyoming might affect downstream conditions within Montana.
- Relying on existing water quality and flow data for conditions at the state line might preclude the use of the model for periods of time when such data are not available.
- Others?

3.2 Configuration of Key Model Components

Configuration of the model itself will involve consideration of four major components: meteorological data, land use representation, hydrologic and pollutant representation, and waterbody representation.

These components provide the basis for the model's ability to estimate flow and pollutant loadings. The data types and sources likely to be used in the model are summarized in Table 2.

Table 2. Summary of data input sources for the modeling.

Data Category	Anticipated Source	Affiliated Agency	Notes
Weather Data	NCDC and NOAA Weather Stations	NCDC and NOAA	Stations located within or in close proximity to the watersheds will be selected (see below)
Land Use/Land Cover	MRLC Satellite Data	USEPA and USGS	Land use data will be updated to the extent possible based on information provided by local officials and landowners and limited field verification.
Stream Network	National Hydrography Database	USEPA and USGS	None
Stream Cross Sections	Derived from Drainage Areas	N/A	Site-specific cross section will be used where available
Flow	Existing gaging stations	USGS	None
Water Quality	Existing stations	USGS, MDEQ, and USEPA	Models will be calibrated to select subset of stations with the longest period of record
Groundwater Quality	Existing Data	DNRC, MDEQ	None
Soils	STATSGO	NRCS	Only soils data available for the entire study area; will be updated to address site-specific conditions where possible
Tongue River Reservoir Bathymetry	Existing Coverage	DNRC	Existing bathymetric map is being evaluated for appropriateness

Meteorological data essentially drive the watershed model. Rainfall and other parameters are key inputs to the model's hydrologic algorithms. The land use representation provides the basis for distributing soils and pollutant loading characteristics throughout the basin. Hydrologic and pollutant representation refers to the HSPF/LSPC modules or algorithms used to simulate hydrologic processes (e.g., surface runoff, evapotranspiration, and infiltration), and pollutant loading processes. Waterbody representation refers to HSPF/LSPC modules or algorithms used to simulate flow and pollutant transport through streams and rivers.

Meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dew point are required to develop a valid model. These data provide necessary input to HSPF algorithms for hydrologic and water quality representation. Meteorological data have been accessed from a number of sources in an effort to develop the most representative dataset for the watersheds.

In general, hourly precipitation data are recommended for nonpoint source modeling in the study area. However, there are a limited number of stations with hourly-recorded data located within the three watersheds. Long-term hourly precipitation data from the National Climatic Data Center (NCDC) weather stations shown in Table 3 will be assessed for use in the watershed model. The NCDC rainfall data should sufficiently represent rainfall variability throughout most of the study area. Some manipulation of the data might be necessary to adequately characterize precipitation at higher altitudes. Data might also be complemented from National Oceanic and Atmospheric Administration (NOAA) stations that are more widespread but only have daily temperature and precipitation data. Rainfall-runoff processes for each of the subwatersheds in the model will be driven by rainfall data from the selected stations (e.g., subwatersheds in the closest proximity to the Broadus station will be driven by this station's data).

Table 3. National Climatic Data Center Weather Stations to be Assessed for use in modeling.

Station ID	Station Name	Begin Date	End Date	Elevation (ft)
WY1165	Buffalo	19480801	20001230	4670
WY7545	Recluse	19480801	20001223	4150
WY8155	Sheridan Airport	19480801	20001231	3964
WY8626	Story	19500401	20001230	5083
MT0330	Ashland Ranger Station	19480702	20001218	3020
MT1127	Broadus	19420101	20001231	3032
MT2689	Ekalaka	19480901	20001227	3425
MT4442	Ismay	19480701	20001226	2500
MT5106	Lodge Grass	19490101	20001231	3413

The watershed model will require a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution will be provided by a land use coverage of the entire watershed.

As discussed in previous reports (MDEQ 2003a; MDEQ, 2003b; MDEQ, 2003c) land use GIS data is available from the USEPA/USGS MultiResolution Land Characteristics (MRLC) Consortium. Activities are currently underway to update these data through a collaborative effort with local government officials and landowners and limited field verification. It is expected that as many as 8 separate land use categories will be represented in the model. Selection of these land use categories will be based on the availability of monitoring data that can be used to characterize individual land use contributions and critical pollutant-contributing practices associated with different land uses. For example, multiple agricultural categories will be represented independently (such as irrigated and non-irrigated croplands), whereas similar grassland/shrubland categories will be grouped.

HSPF/LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. This division will be made for the appropriate land uses in order to represent impervious and pervious areas separately. The division will be based on typical impervious percentages associated with different land use types from the Soil Conservation Service's TR-55 Manual. HSPF/LSPC model algorithms simulating major hydrologic and pollutant loading processes will then be applied to each pervious and impervious land unit. The vast majority of each watershed will consist of pervious land units.

The LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules, which are identical to those in HSPF, will be used to represent hydrology for all pervious and impervious land units (Bicknell et al., 1996). Designation of key hydrologic parameters in the PWATER and IWATER modules of LSPC will be required. These parameters are associated with infiltration, groundwater flow, and overland flow. The STATSGO Soils Database will serve as a starting point for designation of infiltration and groundwater flow parameters. For parameter values not easily derived from STATSGO, documentation on past HSPF applications will be accessed. Starting values will be refined through the hydrologic calibration process (described later in this section).

Pollutant loading processes for various pollutants will be represented for each land unit using the LSPC PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules, which are identical to those in HSPF. These modules simulate the accumulation of pollutants during dry periods and the washoff of pollutants during storm events. Starting values for parameters relating to land-use-specific accumulation rates and buildup limits will be derived from the literature. These starting values will be refined through the water quality calibration process.

Pollutant loading processes for pollutants associated with groundwater returns (e.g., TDS) will be simulated by assigning representative concentrations to groundwater associated with various land uses. Starting values for parameters relating to natural groundwater concentrations will be derived from available data and the literature. These starting values will be refined through the water quality calibration process.

Modeling the entire watershed will require routing flow and pollutants through numerous stream networks. These stream networks connect all of the subwatersheds represented in the watershed model. Routing will require development of rating curves for major streams in the networks, in order for the model to simulate hydraulic processes. Hydraulic formulations typically estimate in-stream flow, water depth, and velocity using continuity and momentum equations. Streams will be assumed to be completely-mixed, one-dimensional segments with a trapezoidal cross-section unless site-specific cross-section information is available. Rating curves will consist of a representative depth-outflow-volume-surface area relationship. In-stream flow calculations will be made using the HYDR (hydraulic behavior simulation) module in LSPC, which is identical to the HYDR module in HSPF. In-stream pollutant transport will be performed using the ADCALC (advective calculations for constituents) and GQUAL (generalized quality constituent simulation) modules.

3.3 Model Calibration and Validation

After initially configuring each watershed model, model calibration and validation will be performed. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. The calibration will be performed for different LSPC modules at multiple locations throughout the watershed. This approach will ensure that heterogeneities are accurately represented. The model validation will be performed to test the calibrated parameters at different locations or for different time periods, without further adjustment. Upon completion of the calibration and validation at selected locations, a calibrated dataset containing parameter values for each modeled land use and pollutant will be developed.

Calibration and validation will be completed by comparing time-series model results to monitoring data. Output from the watershed model will be in the form of hourly/daily average flow and hourly/daily average concentrations for the modeled pollutants for each of the subwatersheds. Flow and water quality monitoring data are available at stations located throughout the watershed as documented in previous reports (MDEQ 2003a; MDEQ, 2003b; MDEQ, 2003c).

Hydrology will be the first model component calibrated, and it will involve a comparison of observed data from in-stream USGS flow gauging stations to modeled in-stream flow and an adjustment of key hydrologic parameters. Gaging stations representing relatively small subwatersheds in diverse hydrologic regions of the watershed will be used for calibration. The calibration year(s) will be selected based upon an examination of annual precipitation variability and the availability of observation data. The period will be determined to represent a range of hydrologic conditions: low, mean, and high flow conditions. Calibration for these conditions is necessary to ensure that the model will accurately predict a range of conditions for a longer period of time.

Key considerations in the hydrology calibration will include the overall water balance, the high-flow-low-flow distribution, storm flows, and seasonal variation. At least two criteria for goodness of fit will be used for calibration: graphical comparison and the relative error method. Graphical comparisons are extremely useful for judging the results of model calibration; time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy will primarily be assessed through interpretation of the time-variable plots. The relative error method will be used to support the goodness of fit evaluation through a quantitative comparison. A small relative error indicates a better goodness of fit for calibration.

After calibrating hydrology at multiple locations, independent sets of hydrologic parameters will be developed and applied to the remaining subwatersheds in the basin. A validation of these hydrologic parameters will be made through a comparison of model output to observed data at additional locations in the watershed. The validation locations are expected to represent larger watershed areas and essentially validate application of the hydrologic parameters derived from the calibration of smaller subwatersheds. Validation will be assessed in a similar manner to calibration.

After hydrology is sufficiently calibrated, water quality calibration will be performed. Modeled versus observed in-stream concentrations will be directly compared during model calibration. The water quality calibration will consist of executing the watershed model, comparing water quality time series output to available water quality observation data, and adjusting pollutant loading and in-stream water quality parameters within a reasonable range. The objective will be to best simulate low flow, mean flow, and storm peaks at water quality monitoring stations representative of different regions of the basin (and different land uses, in particular). The TMDL monitoring stations will be particularly important in calibrating land use-specific pollutant loading parameters.

Adjusted water quality parameters will include pollutant buildup, washoff, and subsurface concentrations. Water quality calibration adequacy will be primarily assessed through review of time-series plots. Looking at a time series plot of modeled versus observed data will provide more insight into the nature of the system and is more useful in water quality calibration than a statistical comparison. Flow (or rainfall) and water quality can be compared simultaneously, and thus can provide insight into conditions during the monitoring period (dry period versus storm event). The response of the model to storm events can be studied and compared to observations (data permitting). Ensuring that the storm events are represented within the range of the data over time is the most practical and meaningful means of assessing the quality of a calibration. Due to the relative lack of water quality monitoring data, statistical comparisons will likely not be made. In the future, after collecting additional data, it may be beneficial to perform error analyses such as correlation (R-squared), Root Mean Square Error, and Mean Absolute Error.

Water quality parameters for the watershed model will be validated through a comparison of observed water quality data to modeled in-stream values. The validation will be performed, to the extent possible, at locations with sufficient water quality observation data located in areas draining large, mixed-land use portions of the watershed.

3.4 Conceptual Discussion of Model Simulation for Existing Conditions and Scenarios

The fully calibrated model will be run for an extended time period to generate flow and pollutant loadings under a variety of conditions. Model output will be summarized to provide insight into average monthly, annual, and seasonal loads under a variety of flow conditions. This information will be used to help understand the current impairment status as well as to perform the TMDL analyses. For waters that are currently impaired, the simulated scenarios will focus on the allocation of load reductions to existing identified sources. For waters that are NOT currently impaired, the simulations will focus on consideration of potential future discharges and development of an equitable allocation scheme that ensures protection of water resources. In all cases, the allocation scenarios to be simulated will be developed in consultation with watershed stakeholders. The sections below describe conceptually how each of the various situations will be handled.

3.4.1 Waters for Which Existing Data Are Inadequate to Make an Impairment Determination

Previous reports (MDEQ 2003a; MDEQ, 2003b; MDEQ, 2003c) have identified a number of data gaps that preclude making an impairment status determination for several of the listed streams in the Tongue River, Powder River, and Rosebud Creek watersheds. Although a rigorous sampling and analysis program is currently being implemented to fill the identified data gaps, there still might be a need to use model output to assist in making the final impairment decisions. For example, MDEQ's numeric criteria for fecal coliforms require that a minimum of five samples be obtained during separate 24-hour periods during any consecutive 30-day period. The data also must be collected when the daily maximum water temperature is greater that 60 °F. Since there are significant logistical challenges associated with collecting enough data to meet these requirements, model output can be used to help supplement the observed data and make a more informed decision regarding the true nature of the water quality.

Modeling output can also be used in other ways to help with impairment status decisions. For example, the provisions of 75-5-306 MCA provide that "*It is not necessary that wastes be treated to a purer condition than the natural condition of the receiving stream so long as the minimum treatment requirements established under this chapter are met*." Natural refers to "*conditions or materials present in the runoff or percolation over which man has no control or from developed land where all reasonable land, soil and water conservation practices have been employed*." These provisions make it impossible to use MDEQ's numeric criteria for making a Clean Water Act 303(d) water quality impairment determination without first defining the natural condition of the receiving stream. The watershed models will be used to assist in this effort by quantifying the pollutant loads from natural and anthropogenic sources.

3.4.2 Currently Impaired by Non-CBM Parameters

Several waters within the Tongue River, Powder River, and Rosebud Creek basins are impaired (or might eventually be determined to be impaired) by non-CBM parameters such as metals, nutrients, sediments, pathogens, and temperature. Modeling will be instrumental in developing any TMDLs determined to be necessary for metals, nutrients, pathogens, and temperature and might provide supplemental information for the sediment TMDLs. For these waters the existing conditions will represent the starting point for TMDL analyses and the following steps will be performed to use the model in TMDL development:

Step 1: Application of the Model to Existing Conditions
This application forms the current condition that is compared to available monitoring information for model testing and calibration.

Step 2: Develop and Test Allocation Scenarios
Working from the baseline condition and considering the results of the source-response analysis, sample allocation scenarios are developed and applied. The results of each scenario are compared with the applicable water quality standard and the scenarios are adjusted until water quality standards (or loading capacity) are achieved. Figure 1 shows how the modeling output can be used to assist in this process.

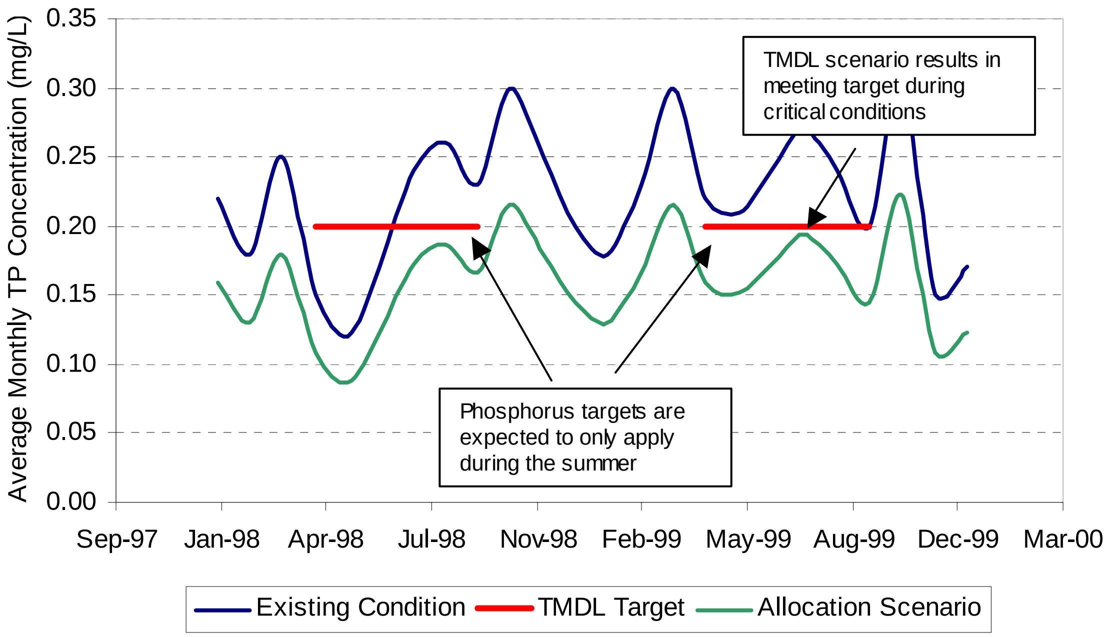

Figure 1. Hypothetical display of how model output can be used in selecting an acceptable allocation scenario.

Step 3: Select Final TMDL Scenario

The final TMDL allocation scenario is selected and results are processed to provide the required TMDL elements. Data processing is needed to provide the annual and monthly load for each category stipulated in the TMDL. Table 4 shows how modeling output can be used to assist in this process. The final scenario model input and output file is saved for the administrative record.

Table 4. Hypothetical display of how model output can be used in allocating loads to the appropriate source categories.

Source	Area (ha)	Existing Total-P Load (kg/y)	Allocated Total-P Load (kg/yr)	Percent Reduction
Row Crop	83,712	52,035	41,628	*20.0%*
Pasture/hay	13,326	1,667	1,667	*0.0%*
Deciduous Forest	7,927	89	89	*0.0%*
Emergent Herbaceous Wetland	79	0	0	*0.0%*
Mixed Forest	60	0	0	*0.0%*
Grassland	51	1	1	*0.0%*
Quarries/Strip Mines	39	47	47	*0.0%*
Small Grain	19	3	3	*0.0%*
Commercial/Industrial/Transportation	1,848	794	794	*0.0%*
Urban/Recreational Grass	1,357	5	5	*0.0%*
Low Intensity Residential	1,032	88	79	*10.0%*

Source	Area (ha)	Existing Total-P Load (kg/y)	Allocated Total-P Load (kg/yr)	Percent Reduction
High Intensity Residential	833	441	397	*10.0%*
GROUNDWATER	0	43,766	43,766	*0.0%*
POINT SOURCE	0	0	0	*0.0%*
TOTAL	110,283	98,936	*88,476*	*10.6%*

3.4.3. Waters Currently Impaired by CBM-Parameters

Several waters within the Tongue River, Powder River, and Rosebud Creek basins are impaired (or might eventually be determined to be impaired) by pollutants associated with CBM development. These pollutants include salinity/TDS/chlorides and SAR. For these waters the existing conditions will represent the starting point for TMDL analyses and the following steps will be performed:

Step 1: Application of the Model to Existing Conditions
This application forms the current condition that is compared to available monitoring information for model testing and calibration. This simulation will include any currently permitted discharges at their current rate of discharge.

Step 2: Source Evaluation
In this application, the model will be used to predict loads from all potentially significant sources, both natural and anthropogenic. Several scenarios will likely be evaluated to attempt to define the "natural" condition.

Step 2: Application of the Model to Existing Conditions with Point Sources at Permit Limits
This application forms the baseline condition that will be reduced to meet the allowable load. Currently permitted dischargers may or may not be currently discharging at their permitted limits. In this step, the simulation will include an analysis of loads at permit conditions using the permitted flow and mean daily concentration allowed for in the permit.

Step 3: Develop and Test Allocation Scenarios
Working from the existing permitted discharge condition, and considering the results of the source-response analysis, sample allocation scenarios are developed and applied. The results of each scenario are compared with the applicable water quality standard and the scenarios are adjusted until water quality standards (or loading capacity) are achieved. Allowable loads will be determined by using a flow-based analysis that considers a range of flows or monthly flow probability, as specified by MDEQ's proposed water quality standards. These will include historic flows (low, average, and high). Different loading capacities for each subwatershed will be identified based on a range of expected flow conditions. Tentatively, it is envisioned that a cap will be set for the loading capacity for each subwatershed to address the possible negative impacts of increased loadings (even if EC/SAR/TDS concentrations remain unchanged) and altered flow regimes. The approach will also address the issue of cumulative loadings within a basin in that the cap for each subwatershed will vary according to what happens in upstream subwatersheds (i.e., CBM development upstream will use up some of the loading capacity for downstream watersheds).

Step 4: Select Final TMDL Scenario
The final TMDL allocation scenario is selected and results are processed to provide the required TMDL elements. Data processing is needed to provide the annual and monthly load for each category stipulated in the TMDL.

3.4.4. Protective TMDLs

Several waters within the Tongue River, Powder River, and Rosebud Creek watersheds are not currently considered impaired for CBM-related parameters. MDEQ intends to develop “protective” TMDLs for these waters because of their threatened status OR as authorized by section 303(d)(3) of the Clean Water Act. The allocations derived from the development of protective TMDLs will facilitate the permitting of future CBM discharges while still ensuring that water quality standards are achieved. The following steps will be performed in developing the protective TMDLs.

Step 1: Application of the Model to Existing Conditions
This application forms the current condition that is compared to available monitoring information for model testing and calibration. This simulation will include any currently permitted discharges at their current rate of discharge.

Step 2: Application of the Model to Existing Conditions with Point Sources at Permit Limits
This application forms the baseline condition that will be reduced to meet the allowable load. Currently permitted dischargers may or may not be currently discharging at their permitted limits. In this step, the simulation will include an analysis of loads at permit conditions using the permitted flow and mean daily concentration allowed for in the permit.

Step 3: Application of the Model to Future Conditions
Future loads from CBM discharges are added to the model as additional point and/or nonpoint source loading contributions. The magnitude of potential future discharges (i.e., future sources) will be estimated based on the results of the EIS (reasonably foreseeable development – RFD) and/or work already completed by MDEQ when they completed their analysis for numeric criteria development.

Step 4: Develop and Test Allocation Scenarios
Working from the baseline condition (Step 3), and considering the results of the source-response analysis, sample allocation scenarios are developed and applied. The results of each scenario are compared with the applicable water quality standard. The scenarios are adjusted until water quality standards (or loading capacity) are achieved. Allowable loads will be determined by using a flow-based analysis that considers a range of flows or monthly flow probability, as specified by MDEQ’s proposed water quality standards. These will include historic flows (low, average, and high), as well as increased flows that can be reasonably expected with new CBM discharges. Allowable loads will also be based on various scenarios that assume the new discharges are coming in different quality conditions. As the assumption of flow/quality of the discharge changes, the TMDL/allowable load will also change. Different loading capacities for each subwatershed will be identified based on a range of expected flow conditions. Tentatively, it is envisioned that a cap will be set for the loading capacity for each subwatershed to address the possible negative impacts of increased loadings (even if EC/SAR/TDS concentrations remain unchanged) and altered flow regimes. The approach will also address the issue of cumulative loadings within a basin in that the cap for each subwatershed will vary according to what happens in upstream subwatersheds (i.e., CBM development upstream will use up some of the loading capacity for downstream watersheds).

Step 5: Select Final TMDL Scenario

The final TMDL allocation scenario is selected and results are processed to provide the required TMDL elements. Data processing is needed to provide the annual and monthly load for each category stipulated in the TMDL. Output will be produced in a format that facilitates future permitting decisions by identifying allowable loads for all reasonably foreseeable flow and loading conditions.

4.0 REFERENCES

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APPENDIX A – 303(D) LISTING INFORMATION

Table A-1. Montana 1996 listing information for the Powder River watershed.

Segment Name	USGS HUC	Estimated Size (mi)	Probable Impaired Uses	Probable Causes	Probable Sources
Lower Powder River	10090209	134	Agriculture Recreation Aquatic Life Support Drinking Water Supply Swimmable Warmwater Fishery	Metals Nutrients Other Inorganics Salinity/TDS/Chlorides Suspended Solids Flow Alteration Pathogens	Agriculture Irrigated Crop Production Natural Sources Petroleum Activities Resources Extraction Range Land Streambank Modification/Destabilization
Little Powder River	10090208	51	Agriculture Recreation Aquatic Life Support Drinking Water Supply Swimmable Warmwater Fishery	Salinity/TDS/Chlorides Other Inorganics Suspended Solids Siltation Flow Alteration	Irrigated Crop Production Natural Sources Streambank Modification/Destabilization
Stump Creek	10090209	4	Aquatic Life Support	Suspended Solids	Agriculture Range Land
Mizpah Creek	10090210	80	Agriculture Recreation Aquatic Life Support Drinking Water Supply Swimmable Warmwater Fishery	Organic Enrichment/DO Other Inorganics Suspended Solids	Irrigated Crop Production Natural Sources Range Land

Source: MDEQ, 1996.

Table A-2. Wyoming 2002 303(d) list for the Powder River watershed.

Name	Location	Cause	Source	Impaired/Threatened Uses
Waterbodies with Water Quality Impairments				
Powder River	South Fork Powder River to below Sussex	Selenium	Undetermined	Warmwater fishery, aquatic life, wildlife
Powder River	From Salt Creek to below Sussex	Chloride	Undetermined	Warmwater fishery, aquatic life
Salt Creek	From the Powder River upstream	Chloride	Undetermined	Nongame fish, aquatic life
Crazy Woman Creek	From the Powder River upstream	Manganese	Undetermined	Drinking water
Waterbodies with Water Quality Threats				
Salt Creek	Downstream from oil fields	Oil spills	Undetermined	Non-game fish, aquatic life
North Fork Crazy Woman Creek	Reaches within T49N R82W	Habitat degradation; Nutrients	Non-point	Coldwater fishery, aquatic life
Hunter Creek	S10 T50N R84W-11 mi. W. of Buffalo	Heavy siltation	Non-point	Coldwater fishery, aquatic life
Rock Creek	Watershed below Forest Boundary, tributary to Clear Creek	Habitat degradation	Non-point	Coldwater fishery, aquatic life
Shell Creek North Fork	Above Shell Creek Reservoir	Habitat degradation	Non-point	Aquatic life
Shell Creek South Fork	Above Shell Creek Reservoir	Habitat degradation	Non-point	Aquatic life
Little Powder River	Wyoming/Montana state line upstream an undetermined distance	Fecal coliforms	Undetermined point	Contact recreation

Source: WDEQ, 2002.

Table A-3. Montana 1996 listing information for Rosebud Creek.

Segment Name	Estimated Size (mi)	Probable Impaired Uses	Probable Cause	Probable Source
Rosebud Creek (Lower and Middle Rosebud Creek)	114	Aquatic life Warmwater fishery	Flow Alteration Suspended Solids Salinity/TDS/Chlorides Other Inorganics Nutrients Metals	Agriculture Natural Sources Irrigated Crop Production

Source: MDEQ, 1996.

Table A-4. Montana 2002 listing information for Rosebud Creek.

Segment Name	Size (mi)	Use Status[a]	Probable Cause	Probable Source
Rosebud Creek - from the mouth 3.8 miles upstream to an irrigation dam (Lower Rosebud Creek)	3.8	Agriculture (not assessed) Aquatic life (partial) Fishery (partial) Industrial (not assessed) Recreation (not assessed)	Bank erosion Other habitat alterations	Removal of riparian vegetation Habitat modification
Rosebud Creek - from the Northern Cheyenne Reservation boundary to the irrigation dam (Middle Rosebud Creek)	105.8	Agriculture (not assessed) Aquatic life (not assessed) Fishery (partial) Industrial (not assessed) Recreation (not assessed)	Other Nutrients	Dam construction Hydromodification
Rosebud Creek – Northern Cheyenne Reservation	73.5	Agriculture (not assessed) Aquatic life (not assessed) Fishery (not assessed) Industrial (not assessed) Recreation (not assessed)		
Rosebud Creek – from the headwaters to the southern border of the Northern Cheyenne Reservation (Upper Rosebud Creek)	22.8	Agriculture (not assessed) Aquatic life (not assessed) Fishery (not assessed) Industrial (not assessed) Recreation (not assessed)		

[a]Not all uses have been assessed.
Source: MDEQ, 2002a.

Table A-5. Montana 1996 listing information for the Tongue River watershed.

Segment	Size (mi)	Impaired Uses	Probable Cause	Probable Source
Tongue River (WY border to Tongue River Reservoir) (Tongue River Above Reservoir)	4	Agriculture Aquatic life Coldwater fishery	Flow alteration	Agriculture Irrigated crop production Natural sources
Tongue River Reservoir	3,500 acres	Aquatic life Coldwater fishery Swimmable	Nutrients Organic enrichment/ dissolved oxygen Suspended solids	Agriculture Municipal point sources
Tongue River (TRR Dam to the confluence with Hanging Women Creek) (Upper Tongue River)	31	Aquatic life Coldwater fishery	Flow alteration	Agriculture Flow regulation Irrigated crop production

Segment	Size (mi)	Impaired Uses	Probable Cause	Probable Source
Tongue River (Hanging Women Creek to diversion dam) (Middle Tongue River)	117.6	Agriculture Aquatic life Warmwater fishery	Flow alteration Metals Other inorganics Salinity/TDS/chlorides Suspended solids	Agriculture Flow regulation Irrigated crop production Natural sources
Tongue River (diversion dam to mouth) (Lower Tongue River)	20.4	Agriculture Aquatic life Warmwater fishery	Flow alteration Metals Other inorganics Salinity/TDS/chlorides Suspended solids	Agriculture Flow regulation Irrigated crop production Natural sources
Hanging Woman Creek	30	Agriculture Aquatic life Warmwater fishery	Flow alteration Metals Salinity/TDS/chlorides	Agriculture Irrigated crop production Natural sources
Otter Creek	53	Agriculture Aquatic life Warmwater fishery	Metals Other habitat alterations Salinity/TDS/chlorides Suspended solids	Agriculture Road/bridge construction Land development Natural sources
Pumpkin Creek	87	Agriculture Aquatic life Warmwater fishery	Flow alteration Salinity/TDS/chlorides Thermal modifications	Agriculture Irrigated crop production

Source: MDEQ, 1996.

Table A-6. Montana 2002 listing information for the Tongue River watershed.

Segment	Size	Use	Use Status[a]	Probable Cause	Probable Source
Tongue River Reservoir	3,500 acres	B-2	Aquatic life (partial) Cold water fish (not assessed) Drinking water (not assessed) Swimming/recreation (partial) Agricultural (full) Industrial (full)	Algal growth/ chlorophyll-*a*	Domestic wastewater lagoon Agriculture
Tongue River from the diversion dam to the mouth	20.4 mi	B-3	Aquatic life (partial) Warm water fish (partial) Drinking Water (not assessed) Swimming/recreation (partial) Agricultural (full) Industrial (full)	Flow alteration	Dam construction Flow regulation/ modification Hydromodification
Hanging Woman Creek from Stroud Creek to the mouth	18.5 mi	C-3	Aquatic life (partial) Warm water fish (partial) Swimming/recreation (not assessed) Drinking water (not assessed) Agricultural (not assessed) Industrial (not assessed)	Siltation	Grazing Agriculture

[a]Not all uses have been assessed.
Source: MDEQ, 2002.